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Collection of aerosols in HEPA filters

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COLLECTION OF AEROSOLS IN HEPA FILTERS

R.P. Pratt and B.L. Stewart

Abstract

The investigation of the performance of HEPA filters of both minipleat and conventional deep pleat designs has continued at Harwell. Samples of filters from several manufacturers have been tested against the UKAEA/BNF plc filter purchasing specification. No unexpected problems have come to light in these tests, apart from some evidence to suggest that although meeting the specification minipleat filters are inherently weaker in burst strength terms than conventional filters. In addition tests have been carried out to investigate the dust loading versus pressure drop characteristics of both designs of filters using a range of test dusts - ASHRAE dust, carbon black, BS 2831 No 2 test dust and sodium chloride.

Initial results(1) previously reported suggested that the early claims for improved dust holding combined with higher air throughputs were exaggerated and concluded that designers would need to choose between reduced plant room size or reduced filter useage. Subsequent work has reinforced this view.

In parallel with this laboratory test work a more fundamental study on the effects of geometric arrangement of filter media within the filter frame has been carried out on behalf of the UKAEA by Loughborough University. The results of this study has been the development of a mathematical model to predict the dust load versus pressure drop characteristic as a function of filter media geometry. This has produced good agreement with laboratory test results using a challenge aerosol in the 1-5um size range. Further observations have been made to enhance understanding of the deposition of aerosols within the filter structure.

The observations suggest that the major influence on dust loading is the depth of material collected in the flow channel as a surface deposition, and this explains the relatively poor performance of the minipleat design of filter. Another factor affecting performance is the velocity distribution within the filter which causes preferential deposition of the aerosol at the channel inlet, particularly in the minipleat design, which in turn leads to premature blockage at the opening of the pleats.

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ILLUSTRATIONS

1. Introduction

Filters used in the United Kingdom Atomic Energy Authority and British Nuclear Fuel nuclear plants are purchased against a specification[2] which lays down requirements for materials of construction and general performance criteria. However, it does not cover evaluation or performance requirements regarding the life of the filter. As a matter of routine measurements are made of the dust loading versus pressure drop characterisic of filters supplied for test, as part of the burst strength evaluation of the filter through dust accumulation. Typically either BS 2831[3] No 2 test dust, an alumina test dust of 5 micrometre mean particle size, or carbon black, inherently of sub micron particle size, have been used for this purpose.

More recently considerable interest has been generated in the dust holding capacity of filters, principally though the growing technical and financial implications of radioactive waste treatment and disposal. A study has been started to examine more scientifically the effects of geometry and media areas on the dust holding capability of HEPA filters. The availability of minipleat or high capacity filters which meet the purchasing specification and promise significant savings in plant room costs and/or reductions in filter useage has stimulated interest in this area.

A research programme has been sponsored by UKAEA Harwell at Loughborough University to study geometric, air velocity and inertial effects on the dust holding versus pressure drop characteristic of HEPA filters. In addition tests have been carried out at Harwell using a highly characterised, sub micron test dust on 3 different designs of filters currently available commercially using the same media to determine whether significant advantages in terms of dust holding are offered by one of the designs.

2. Routine Dust Load versus Pressure Drop Testing

On a routine basis, strength tests have been carried out on a number of filters supplied against the purchasing specification by loading filters with characterised test dusts . Two test dusts have been used. BS 2831 test dust Number 2, and carbon black. The BS No 2 test dust is a well-characterised alumina dust, and consists principally of particles in the size range 3.5 - 7.0 micrometres, with 99.5% finer than 13um and 2% finer than 2.5um. The carbon black dust is inherently sub micron but prone to aglomeration.

The alumina dust is dispersed from a rotating feed cap by a compressed air ejection nozzle, which ensures adequate dispersal. Two different dispensers have been used for carbon black, the standard ASHRAE dispenser, and an in-house dispenser design in which the carbon is airated within a glass sphere before being ejected by a slight over-pressure from the sphere into the air stream.

The test rig used for all tests was designed to meet the requirements of BS 2831 (Fig 1). It consists of a simple circular duct, open ended to receive the discharge from the dust dispenser, a standard filter housing, and downstream length of duct to the extract fan. Air flow rates are controlled by a damper and measured with an orifice plate. The differential pressure generated across the filter is measured with a manometer. The quantity of test dust fed into the rig is weighed before it is loaded into the dispenser.

All filters tested in this programme were operated at their nominal rated flow. Two types of filter were tested, conventional deep pleat filters, rated flow 1700 m^3/h, and minipleat filters, rated flow 3400 m^3/h.

Deep pleat filters from 4 suppliers and minipleat filters from 5 suppliers have been tested. Although supplied against the purchasing specification, the minipleat filters were constructed from a variety of media grades. However all the deep pleat filters were constructed from the same filter media, Evans Adlard F39ZR.

The results tabulated below (Table 1), and given graphically in Fig 2 (BS No 2 dust) and Fig 3 (carbon black) show the wide variation in dust holding recorded. It can be seen that the results of the tests using BS No.2 dust show no clear advantage in dust holding for the minipleat filters, in spite of their having significantly greater areas of filter media. Surprisingly the tests with the carbon black show the deep pleat filters hold considerably more dust than the minipleat filters.

Although the carbon black is intrinsically of sub micron form, difficulty was experienced in producing good dispersion of the individual particles from both dispensers. There is evidence to suggest that significant aglomeration of the carbon black particles occurred.

Examination of the filters after loading showed some bridging of the minipleat panels with both the alumina and carbon black dusts. Also significant deposition of the carbon black occurred on the media adjacent to the aluminium spacers in the deep pleat filters (Fig.4). These two factors are the likely cause of relatively poor dust holding capacity of the minipleat filter relative to the deep pleat design for the aglomerated carbon black aerosol.

3. Investigation into Media Arrangement effects for Sub Micron Aerosols

As the main challenge to HEPA filters is likely to be a sub micron aerosol, a series of tests were carried out to investigate whether any of the media arrangements available in HEPA filter form offered advantages in terms of sub micron dust holding capacity.

Table 2 gives the basic parameters of the four types of filters evaluated. All filters were produced from the same filter media, Evans Adlard F39ZR.

The test dust selected for these tests was sodium chloride, generated using the portable in-situ filter test generator developed by CDE Porton Down. The aerosol is produced by vaporising sticks of sodium chloride in an oxy-propane flame, which gives an aerosol of 0.14 micrometers mean particle size as measured on a LAS-X laser particle analyser. The aerosol was generated at a rate of 1.4 grams per minute.

In order to reduce the number of variables possibly affecting any results, it was decided to load the filters at a media face velocity of 1.5 m/min. This corresponds to the face velocity inferred in the purchasing specification which lays down a requirement of a minimum of 4 m^2 of media per 360 m^3/h of rated air flow. This new requirement arose during a revision of the specification in 1982.

Table 1 Dust Load, Pressure Drop Test Results - Commercial Filters

Filter Type	BS No 2 Dust load (kilograms)						Carbon Black dust Load (grams)					
Δp Pascals	400	600	800	1000	1200	1400	400	600	800	1000	1200	1400
Deep Pleat												
Type 1	1.9	5.0	6.5	8	9	10	300	570	720	820	900	930
Type 2	1.2	4.0	6.1	8	9	12	340	600	740	810	870	900
Type 3	6.0	10.0	13.0	15.0	17.0	19	600	760	880	940	990	1020
Type 4	2.3	4.3	6.0	7.7	9.2	10.6	210	380	510	610	680	740
Minipleat												
Type 5	0.65	4.0	5.7	6.9	7.8	8.5	150	170	240	300	325	340
Type 6	2.4	5.4	7.2	8.6	9.6	10.4	120	160	210	270	310	340
Type 7	-	-	-	-	-	-	160	300	390	430	450	460
Type 8	4.4	8.0	10	10.5	11.51	11.9	-	-	-	-	-	-
Type 9	4.0	8.0	11	13	15	16	-	-	-	-	-	-

TABLE 2 Filter Types tested with Sub Micron Aerosols

Type	Description	Physical Size mm	Media Area m^2	Air Flow Rate at 250 Pa Δp m^3/h	Media Face Velocity @ Rated Flow m/min
A	Deep Pleat	610x610x290	20.4	1850	1.51
B	Minipleat (12 panels)	610x610x290	26.2	2500	1.59
C	Minipleat (16 panels)	610x610x290	35	3000	1.43
D	Panel filter	610x610x120	18.3	1500	1.37

The test rig used was as described in Section 2.

The pressure drop versus air flow rate of the 4 filters tested is given in Fig.5. Of interest is the fact that the 16 panel minipleat filter has only a 17% increase in rated flow in spite of having some 30% more media. The reason for this is obvious from Fig.6, which gives the media face velocity versus pressure drop characteristic. The variations in pressure drop for a given face velocity give an indication of the efficiency with which the media is laid up in the filter case. The difference between the media and filter values is attributable to flow channel losses and entrance effects. As a reference the characteristic of the media in plain sheet form is also plotted.

The dust loading versus pressure drop characteristic for the four filters tested is given in Fig.7. The advantages of the increased media area of the 16 panel minipleat filter is obvious. In order to examine this characteristic more closely, the dust load per unit area of media versus pressure drop for the four filters has been calculated and given in Table 3. This shows that, for sub micron aerosols, in terms of dust holding capacity there is no significant advantage to be gained from any of the four arrangements tested.

In order to examine the effects of face velocity on dust holding capacity, sections of a minipleat and deep pleat filter were exposed in turn to the sodium chloride aerosol at a face velocity through the media of 1.8 m/min and 1.2 m/min compared with the reference 1.5 m/min. The results are plotted in Fig. 8 in which the dust holding capacities are given relative to that of the deep pleat filter with a media face velocity of 1.8m/min and a maximum differential pressure of 1000 Pa. These show that a considerable advantage can be gained in terms of filter life if the filter unit is down rated, the increases in dust holding capacity over this face velocity range is between 1.6 to 2.0 depending on the filter type and maximum pressure drop developed across the filter.

4. R & D Programme at Loughborough University

The results of this Harwell sponsored three year study will be published in full elsewhere[4]. However, some of the conclusions more relevant to this paper are included here.

Table 3 Dust Load v Pressure Drop as a function of Media Area

Filter Type	Δp Pascals	Dust load g NaCl	Dust load/unit area g/m^2
A - Deep Pleat - 20.4 m^2 media	400	20	1.0
	600	45	2.21
	[illegible]	[illegible]	[illegible]
	1000	[illegible]	[illegible]
B - Minipleat 12 panel 26.2 m^2 media	400	27	1.0
	600	57	2.18
	800	86	3.28
	1000	116	4.43
C - Minipleat 16 panel 35 m^2 media	400	30	0.9
	600	80	2.29
	800	123	3.51
	1000	160	4.57
D - Panel 18.3 m^2 media	400	15	0.8
	600	40	2.19
	800	60	3.27
	1000	81	4.4

The dust chosen as the basis of this programme was the BS No.2 test dust. It is readily available in a well characterised form and relatively easy to dispense. It also covers the particle size range at which inertial and gravitational effects are likely to be significant without including particles of large sizes unlikely to be found in the majority of extract systems.

Although a significant part of the programme was carried out using flat sheets of paper, tests were also carried out on sections of minipleat and deep pleat filters. The dust loading results cannot be directly compared quantitatively with the results of the Harwell work, as the minipleat filters used were not constructed from the same filter media.

4.1 Deep Pleat Filters

The tests carried out on the deep pleat filter enabled the following conclusions to be reached:-

- Dust distribution along the individual flow channels was generally uniform in particle size and quantity, except for some local effects at the channel entrance where an increase in deposition of up to 30% was found.

- Ridges of dust had collected where the spacer meets the filter media and on the lower spacer surface. Size analysis showed this deposition to contain larger particles than that deposited on the filter media, which suggests that gravitational sedimentation is significant where particles exceed 5 micrometres diameter.

Mathematical models are being developed based on these results, which should enable a parametric study to be made to optimise flow channel dimensions in terms of dust collection and pressure drop of complete filter units.

4.2 Minipleat Filters

For the minipleat filters, the tests carried out suggest that:-

- Dust deposition is not uniform within the panels.
- Significant dust is collected on the face of the panel as well as within the flow channels and also the dust accumulates preferentially on the downstream edges of each sub-flow channel adjacent to the spacer threads.
- The dust collected on the face of the panel is of larger particle size than that deposited within the flow channel, suggesting inertial separation.
- After a considerable dust burden is collected, the flow channel entrances close up entirely with the exception of holes of formed though the dust cake through which the air enters the flow channel. Eventually dust builds up round the hole entrance creating a beehive effect (Fig.9).

Because the dust deposition and inertial effects vary during the duration of the loading process predictive modelling is somewhat more difficult and is proving less successful than for the deep pleat filters.

5. Conclusions

It has been shown mathematically[4] that over the range of air velocities associated with HEPA filtration the deposition of sub micron aerosols is not affected by inertial effects resulting from velocity varations within the filter assembly. The tests carried out using the 0.14um NaCl aerosol reinforces this conclusion in that dust holding capacities of the filter designs tested was purely a function of filter media area used in the filter element construction.

The minipleat filter design allows more filter media to be contained within the 610 x 610 x 290 mm filter size, and therefore in cases where the aerosol challenge is predominantly sub micron, for example in secondary and tertiary filter banks, they offer the potential of reduced filtration plant size and a reduction in the number of filters for disposal.

The variations in dust holding capacity as a function of face velocity are significant and, when filter life is an important criteria, either through disposal costs or changing difficulties, the use of down-rated filters might be considered cost effective, although this would inevitably be at the expense of plant room size and therefore capital costs.

The pressure drop versus media face velocity results indicate that between 54 and 98 pascals of pressure drop are accounted for by losses in the flow channels of the filters, at a media face velocity of 1.5m/min. This is a significant proportion of the total pressure drop across the filter of some 250 pascals. Obviously the flow channels could be increased to reduce these losses, particularly in the panel filter, but only at the expense of reducing the media area built into the filter, with commensurate increases in media face velocity and hence pressure drop through the media. However, this option would affect detrimentally the dust holding capacity of the filter, which as we have seen is proportional to the media area and inversely proportional to media face velocity for sub micron aerosols. Also affected would be the collection efficiency of the filters which is itself a function of media face velocity(5).

A study of these various interacting parameters should lead to the emergence of filters designed against specific requirements. For example, the filter design could be aimed at maximising the rated flow of the filter which would lead to a reduction in plant size and therefore capital cost. Alternatively, by producing a filter with more filter media and hence a lower media face velocity, its dust holding capacity could be increased which would lead to a reduction in filter usage and generation of active waste requiring expensive treatment and disposal. Of course, some optimisation between these extremes might be appropriate to provide a more cost effective design of active ventilation systems.

The comparative tests using BS No 2 test dust (5 m mean particle size) do not suggest any advantage is gained from using high capacity minipleat filters over the conventional deep pleat filters in spite of their enhanced filter media area. The Loughborough University studies suggest mechanisms which support these results, the principal effects being the inertial deposition of aerosol on the face of the minipleat panels which leads to premature bridging of the flow channels,and the advantageous collection by gravitational separation onto the spacers of the deep pleat filters.

Although all the deep pleat filters complied with the purchasing specification, and were made from the same media grade, at the time there was no stated requirements on media area, so that the various suppliers were free to optimise media area, and flow channel size to produce filters of the appropriate clean pressure drop and rated flow. The wide range of the dust holding capacities of the deep pleat filters is therefore probably the effect of variations in filter media area incorporated in the filters.

The results of tests on the minipleat filters were similarly disparate. Undoubtedly this is due to the variations in media grade, pleat dimensions and media area, although once again all filters tested met the performance criteria of the specification.

The results of the carbon black loading tests cannot easily be explained as it is basically a sub micron material. Difficulties were experienced in dispersing the carbon black. There was also evidence that aglomeration of the particles occurred. Significant quantities of aglomerated material was found lying in the deep pleat filter flow channels, and early bridging across the minipleat panels was evident. It could be argued that these comparative results are best ignored as being directly attributable to the characteristics of the test dust, but one should remember that precisely this type of aerosol can be generated from a fire, and hence the rapid blocking of the minipleat filters under these conditions could be a factor in the deliberations over choice of filters in cases where fire risk is significant.

The research programme at Loughborough University was designed to examine the parameters affecting the collection of aerosols within a complete filter, with a longer term aim of developing and validating design codes to optimise filter design for both minipleat and deep pleat filters. Some success has been achieved for the deep pleat filters; the deposition mechanisms for the minipleat filters particularly inertial effects on dust collection on the face of the filter panels, are very complex and interactive and therefore mathematical modelling has not yet reached a successful conclusion. The work complements the tests on complete filters using BS No 2 test dust and has helped explain some of the mechanisms involved in aerosol collection. Further experimental work is required to fully validate the design codes for the deep pleat filters and to offer a better understanding of the collection mechanisms appertaining to minipleat filters.

ACKNOWLEDGEMENTS

The authors wish to record their thanks to Dr J I T Stenhouse and R Owen for the work carried out at Loughborough University, and Mitchell Cotts Air Filtration for manufacturing filters for test.

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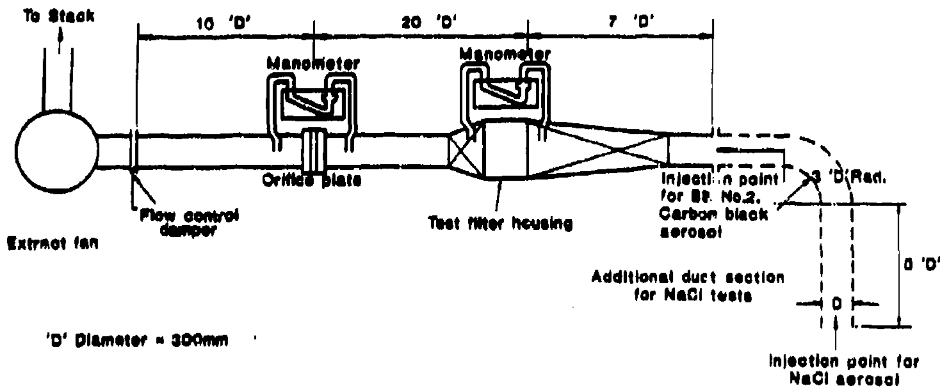
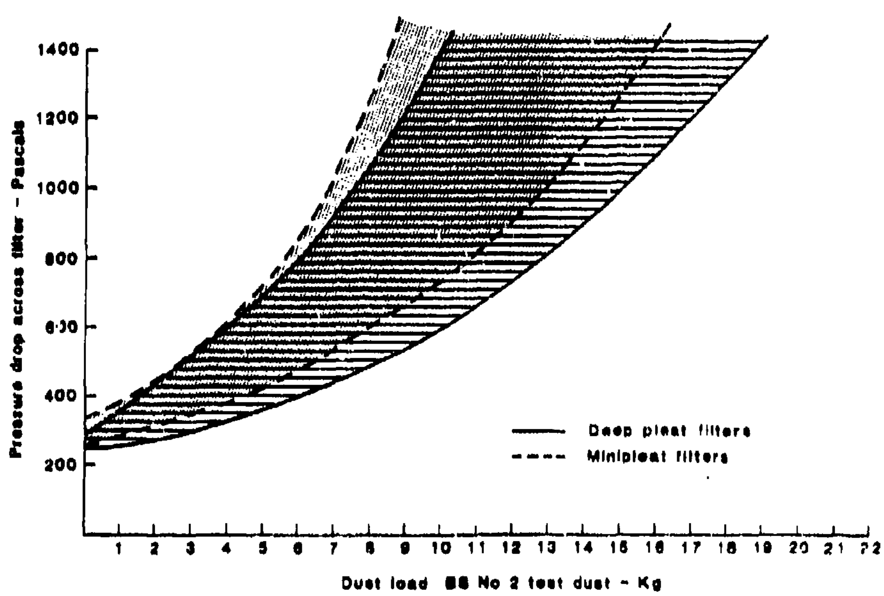
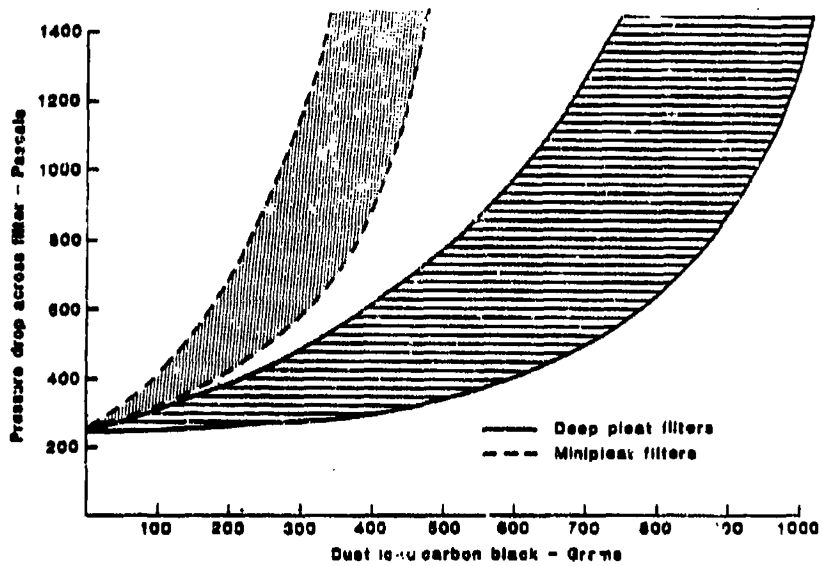


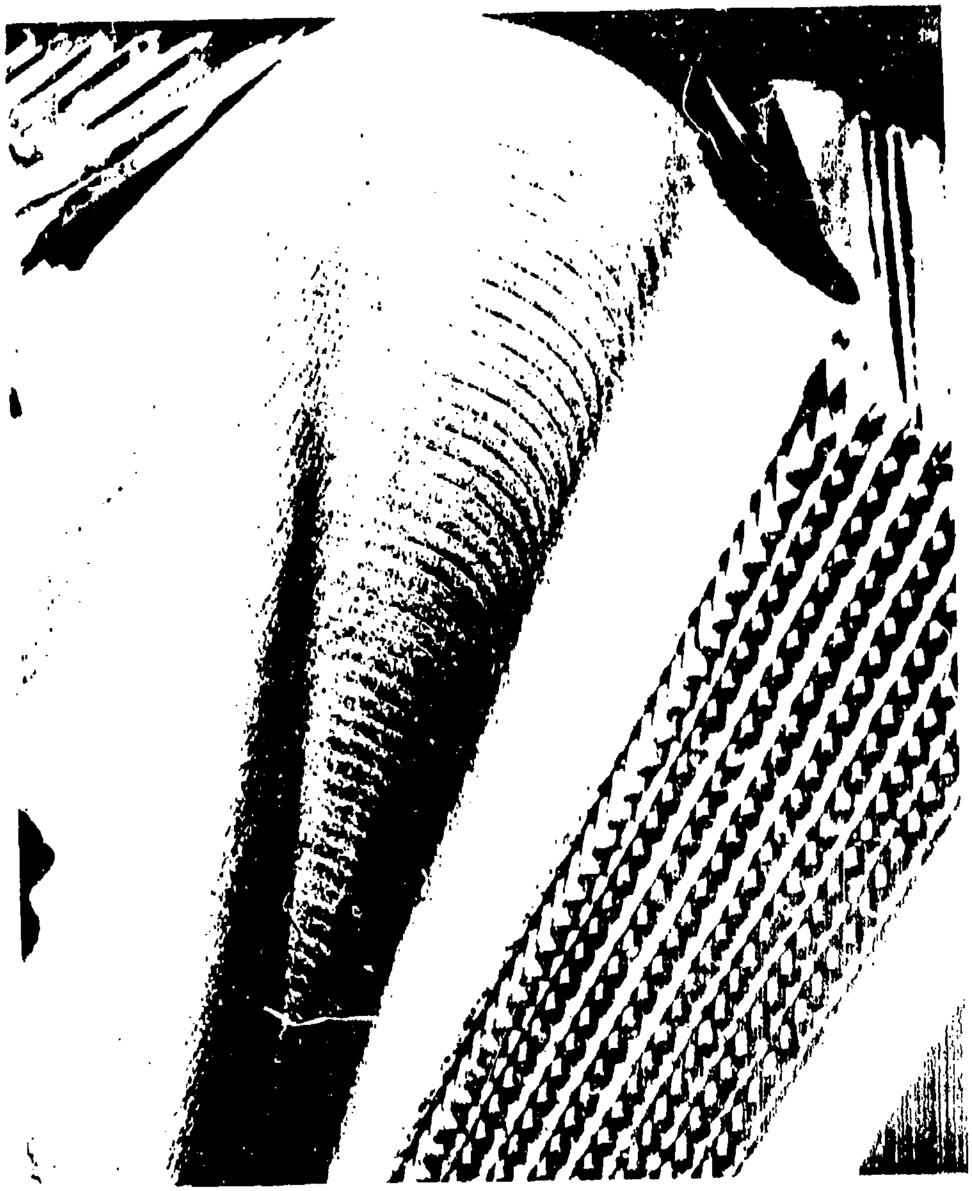
AERE R 12323 Fig. 1
General arrangement of test rig



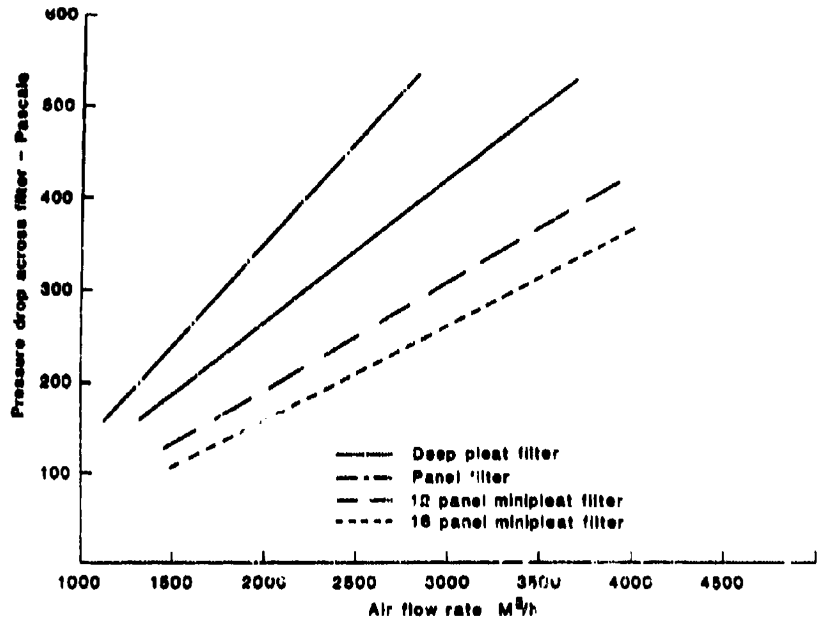
AERE R 12323 Fig. 2
Dust load v pressure drop – BS No. 2 test dust



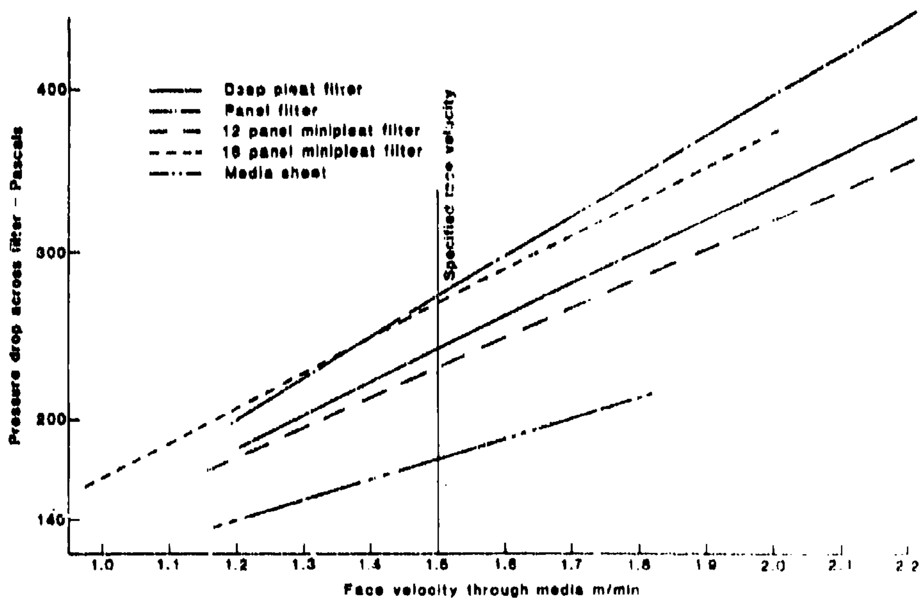
AERE R 12323 Fig. 3
Dust load v pressure drop – carbon black test dust



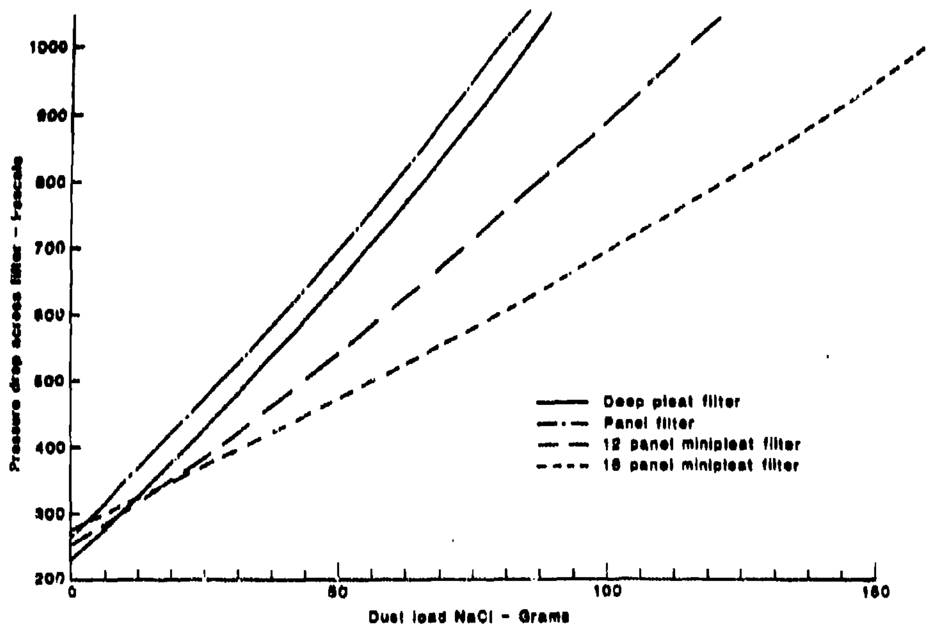
AERE R 12323 Fig. 4
Deposition of carbon black on deep-pleat filter



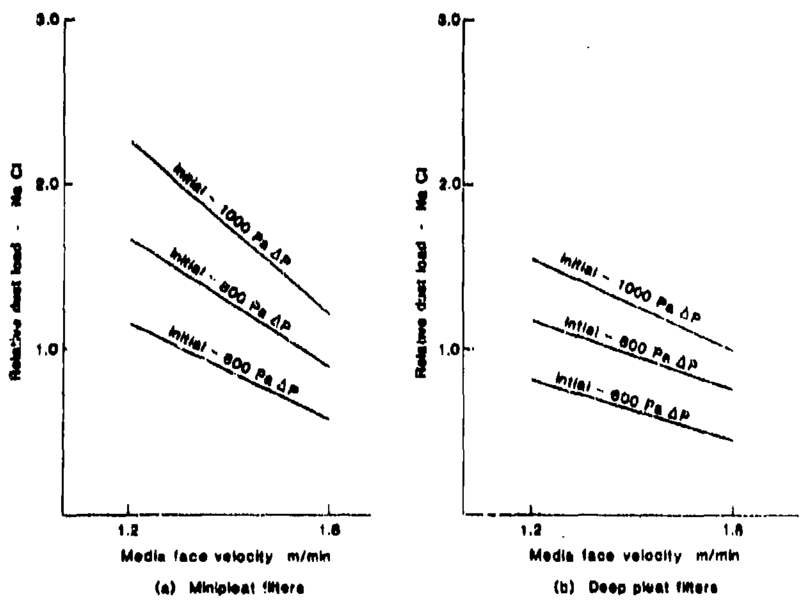
AERE R 12323 Fig. 5
Air flow v pressure drop



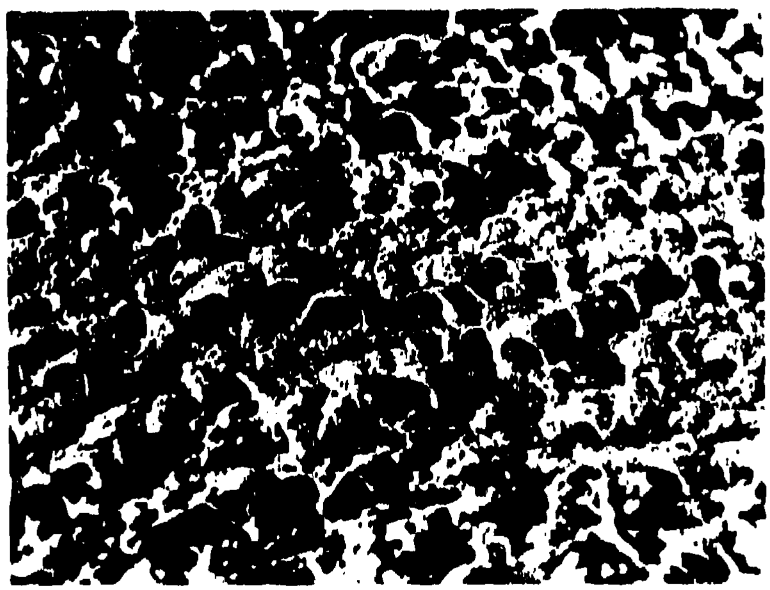
AERE R 12323 Fig. 6
Media face velocity v pressure drop



AERE R 12323 Fig. 7
Dust load v pressure drop NaCl test dust at 1.5m/min face velocity



AERE R 12323 Fig. 8
Relative dust loading v media face velocity



AERE R 12323 Fig. 9
Beehive formation of dust deposition on minipleat filter panel

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